Observation of parametric radiation from 400 GeV/c protons in Si crystals

Our goal
Study possibility to control the state of a crystal collimator by PXR

After theoretical predictions at 1971, the PXR has been detected and investigated on electron beams of various energies

PXR from relativistic electrons is a perspective source of X-rays because of its high monochromatism and directivity

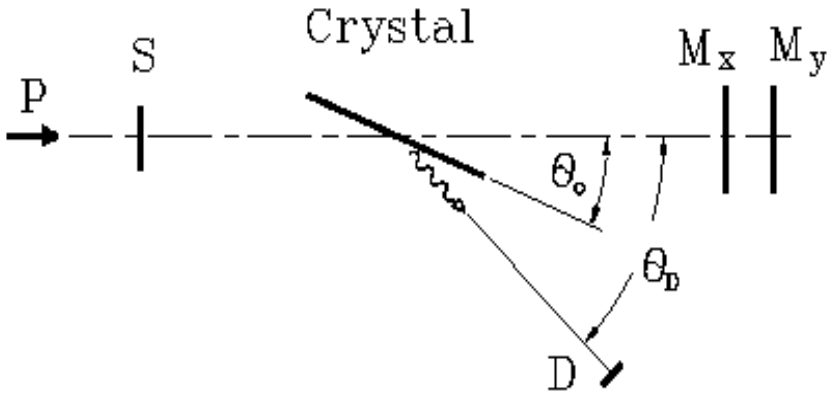
First observation of PXR spectra from heavy particles was made in Dubna with 5 GeV protons and 2.2 GeV/u carbon nuclei

In our experiment
PXR spectra from 400 GeV/c protons were successfully observed for different crystals and geometries

Nature of PXR

Virtual photon field is associated with a fast charged particle

Diffraction of virtual photons on the crystal planes produces real photons



Energies of PXR photons are determined by diffraction condition

$$E_n = n\frac{2\pi\hbar c}{d}\frac{\beta\sin\theta_B}{1-\sqrt{\varepsilon}\,\beta\cos\theta_D},$$

PXR intensity should be proportional to particle charge Z^2

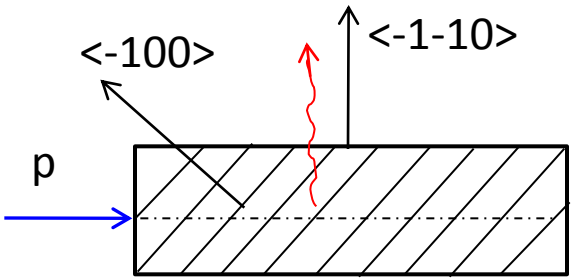
Indication of this was observed with carbon nuclei in Dubna experiment

PXR in Si strip crystals with (110) deflecting planes

(110) planes are parallel to the crystal large faces
They were aligned with the proton beam

PXR was generated by diffraction of virtual photons of protons on (100) planes with inclination of θ_b=45˚ to (110) planes

PXR photons are emitted in direction normal to the beam at θ_d=90˚



Photon energy of first diffraction order E_1=6.47 keV

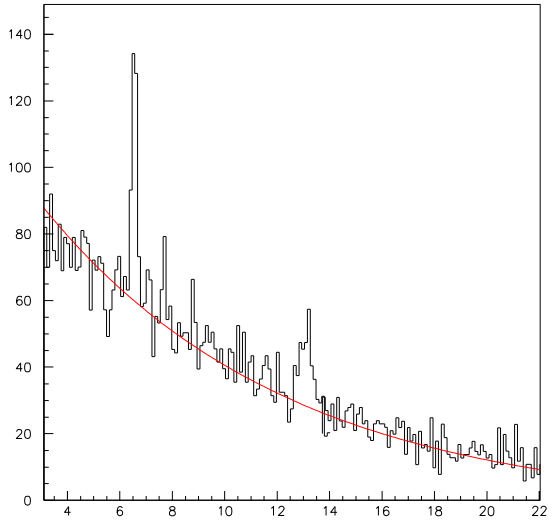
Semiconductor detector was calibrated using Kα line of characteristic radiation generated by protons in copper target

Energy resolution for Kα line was about 250 eV

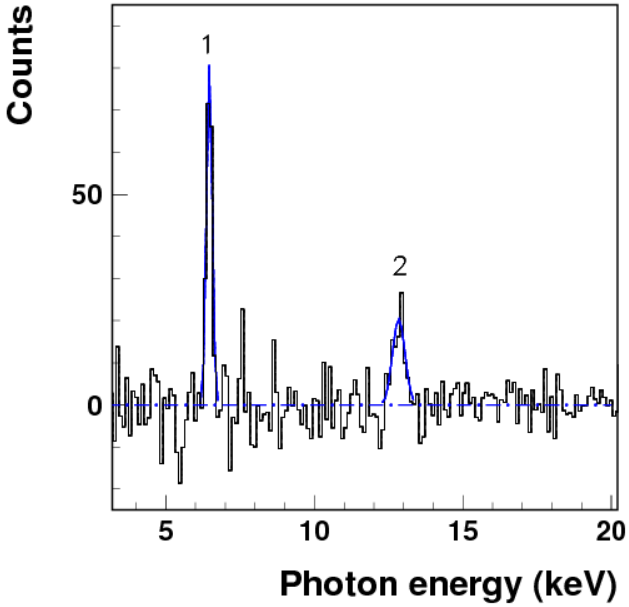
PXR spectra from protons in Si strip crystal

(110) Si strip, 5 mm along the beam with thickness 2 mm

Measured spectrum



Spectrum with background subtraction



Photon energies in maximum and widths are E_1=6.46 keV , σ=95 eV and E_2=12.85 keV, σ=207 eV

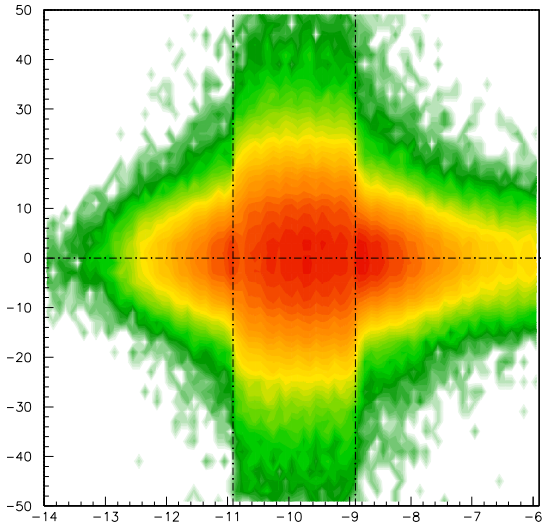
Number of registered photons in the first maximum − N_1=179 and in the second − N_2=101

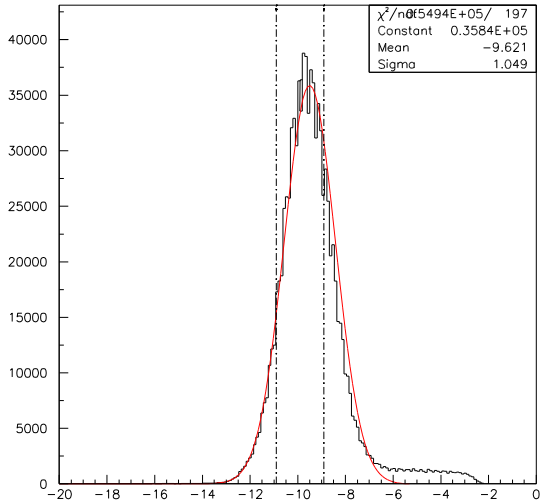
Ratio N_1/N_2 = 1.778

Estimation of PXR intensity from protons in Si strip crystal

Crystal position in the proton beam

Beam fraction covered by the crystal R_{hit}=0.6246





Attenuation length of PXR photons E1 and E2 → L_1=36 5μm and L_2=268 μm

Trigger number during the measurement N_{tr}=578.4 ×10^6

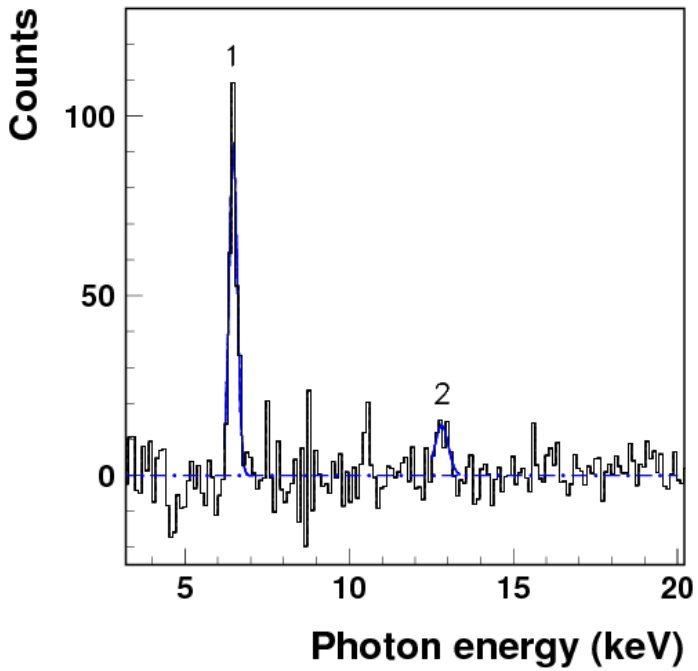
Number of particles hit the crystal $N_{hit}=N_{tr} \times R_{hit}$=361 ×$10^6$

PXR intensity → $I_1=N_1/N_{hit}$=5 ×10^{-7} and I_2=2.8 ×10^{-7}

PXR from protons in Si strip crystal − 0.4 mm thickness

Thickness is comparable with attenuation length for PXR photons of second order diffraction − L_2=268 μm

Crystal length along the beam is the same 5 mm



Number of registered PXR photons
N_1=287 and N_2=62

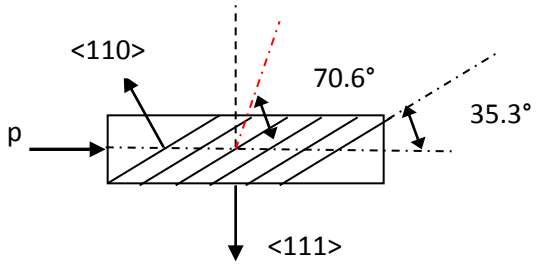
Ratio N_1/N_2 = 4.64

Relative intensity of PXR photons with E_2 becomes smaller because of a smaller crystal thickness

PXR from protons in Si quasimosaic crystal

(111) deflecting planes were aligned with the proton beam

PXR was generated by diffraction of virtual photons of protons on (110) planes with inclination of θ_b=35.3˚ to (111) planes

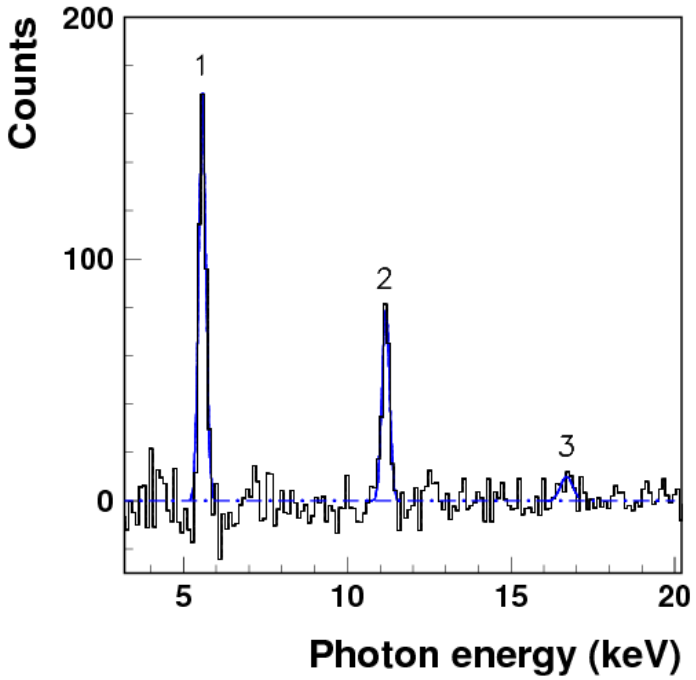


PXR photons are emitted in direction $\theta_d=2\theta_b$=70.6˚ to the beam

Photon energy of first diffraction order E_1=5.58 keV

Transverse dimensions of the crystal are large in this case

PXR spectra from protons in Si quasimosaic crystal



Photon energies in maximum and widths

E_1=5.58 keV , σ=103 eV

E_2=11.18 keV, σ=108 eV

E_3=16.7 keV, σ=182 eV

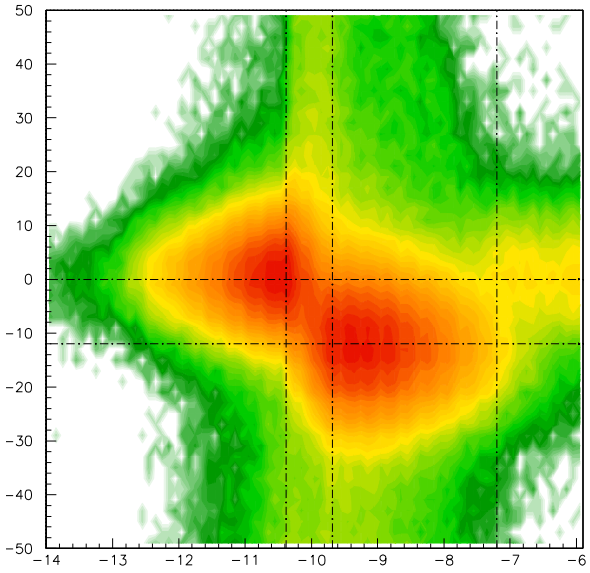
Number of registered photons in the maximums − N_1=420
N_2=230 and N_3=47

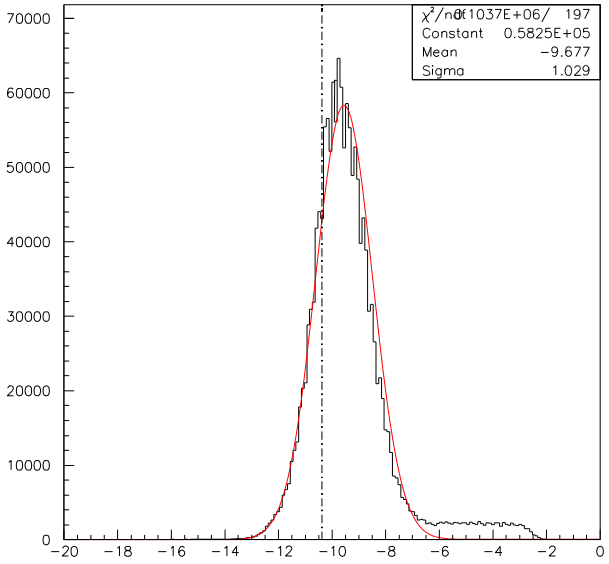
Ratio N_1/N_2 = 1.83 and N_1/N_3=9

Estimation of PXR intensity from protons in Si quasimosaic crystal

Crystal position in the proton beam

Beam fraction covered by crystal R_{hit}=0.7655





Trigger number during the measurement N_{tr}=800 ×10^6

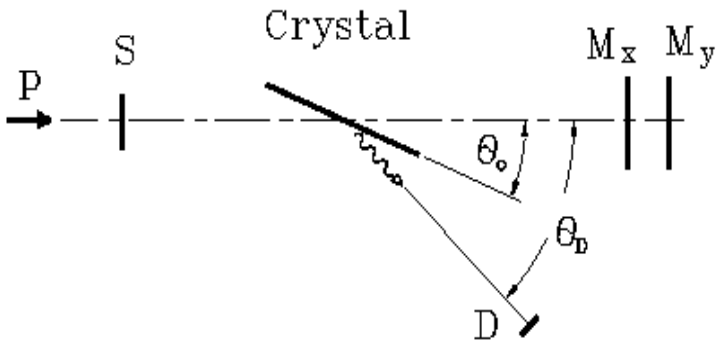
Number of particles hit the crystal $N_{hit}=N_{tr}\times R_{hit}$=612 ×$10^6$

PXR intensity → $I_1=N_1/N_{hit}$=6.84 ×10^{-7} , I_2=3.74 ×10^{-7} and I_3=0.76 ×10^{-7}

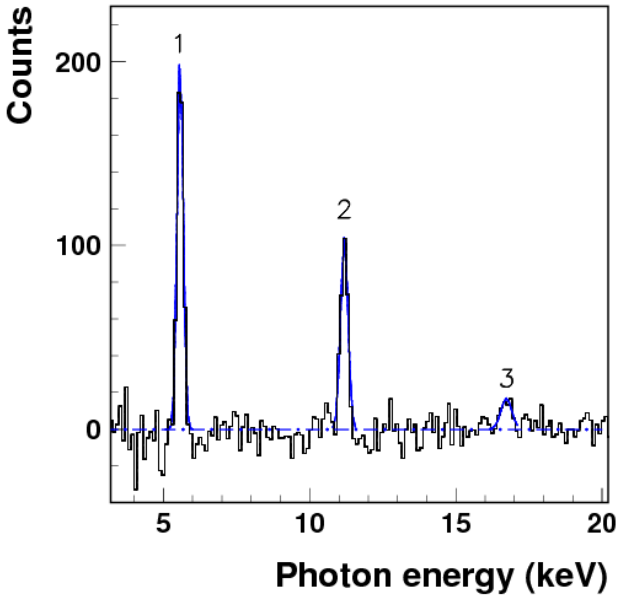
PXR from protons in Si crystal – Bragg geometry

PXR measurements were made with Si strip crystal
with its 35.3˚ inclination to the beam

PXR was generated by diffraction of virtual photons of protons on (110) planes which are parallel to the crystal large faces



Peaks positions are the same as
for QM crystal



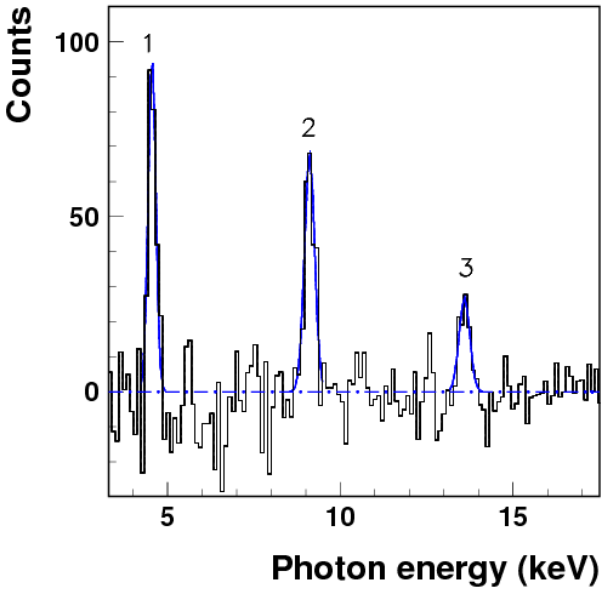
Number of registered photons in the maximums − N_1=497
N_2=303 and N_3=70

Ratio N_1/N_2 = 1.64 and N_1/N_3=7

PXR from protons in Si crystal – Bragg geometry

PXR measurements were made with Si strip crystal
with its 45˚ inclination to the beam

PXR was generated by diffraction of virtual photons of protons on (110) planes and registered by the X-ray detector at the angle $\theta_d=2\theta_b=90^\circ$



Photon energies in maximum and widths

E_1=4.55 keV , σ=108 eV

E_2=9.11 keV, σ=148 eV

E_3=13.6 keV, σ=154 eV

Third maximum is good visible

Number of registered photons in the maximums − N_1=263
N_2=241 and N_3=98

Ratio N_1/N_2 = 1.1 and N_1/N_3=2.7

Conclusion

Observation of PXR emission from 400 GeV/c protons in Si crystals in the geometry of collimation was made

PXR intensity at the first maximum were $I_1 = 5 \times 10^{-7}$ and 7×10^{-7} per proton for strip and quasimosaic crystals, respectively

In the condition of the crystal collimation in the beam pipe intensity should be about $I_1 = 10^{-6}$ per proton because of vacuum and passage through crystal in its surface layer

For lead ions the PXR intensity increases by Z^2 and should be $I_1 > 10^{-4}$